A Comparison of Low Frequency Noise in GaAs and InP-based HBTs and VCOs

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ABSTRACT

The low frequency collector noise spectra for GaAs-based and InP-based HBTs have been measured and compared as a function of emitter material, bias and temperature. $Al_{20}Ga_{80}As$/GaAs and InAlAs/InGaAs HBTs exhibited classic 1/f noise spectra while the $Al_{30}Ga_{70}As$/GaAs HBTs showed a pronounced burst noise component. Identical VCO circuit topologies impemented in $Al_{20}Ga_{80}As$/GaAs and InAlAs/InGaAs HBTs demonstrated a 10 dB improvement in phase noise at a 1 MHz offset over the $Al_{30}Ga_{70}As$/GaAs HBT-based VCO.

INTRODUCTION

Low frequency noise is known to limit the spectral purity and stability of solid-state frequency synthesizers The baseband noise is upconverted to higher frequencies via nonlinear processes and appears as sideband noise (phase noise) around the RF carrier signal [1]-[4]. The components that constitute the low frequency noise are 1/f (flicker) noise and burst noise. These sources are believed to orginate from fluctuations in the occupancy of bulk and surface trap centers and in the surface recombination velocity [5][6]. HBTs show superior low frequency noise characteristics because the main conduction path in HBTs is through bulk material while that in FETs is along abrupt heterointerfaces and exposed surfaces where traps are abundant.

Future millimeter-wave applications such as collision-avoidance radar will require low phase noise components operating at V to W band. InP-based HBTs offer several advantages over GaAs-based HBTs including superior RF performance and a lower surface recombination velocity, making them suitable for high frequency, low noise oscillators. In this study, a direct comparison of the low frequency collector noise spectra of HBTs as a function of emitter material, current density and temperature was performed. The measured phase noise of VCOs implemented in the various HBT technologies confirms the impact of the baseband noise on oscillator performance.

EPITAXIAL STRUCTURE AND FABRICATION

The emitter material and composition have a profound effect on the low frequency noise levels of an HBT. Both GaAs-based and InP-based HBTs were grown and fabricated. The different GaAs-based HBTs had $Al_{30}Ga_{70}As$ and $Al_{20}Ga_{80}As$ emitters graded to the GaAs base and collector regions. The InP-based HBT had an InAlAs emitter graded to the InGaAs base and collector regions.

The fabrication process utilized a self-aligned base metal process to define a small emitter mesa to base metal separation and to minimize the extrinsic collector-base mesa capacitance. The AlGaAs emitter devices featured a thin AlGaAs ledge to reduce the deleterious surface recombination currents that occur in exposed GaAs [7]. An AlGaAs passivation ledge has been shown to improve 1/f noise in HBTs [8]. Ohmic metalizations to the HBT were established with conventional alloyed contacts to GaAs layers and refractory non-alloyed contacts to InGaAs layers. All the structures were encapsulated and passivated with a silicon nitride PECVD layer.

NOISE MEASUREMENT SYSTEM

A schematic of the low frequency noise measurement system is given in Figure 1. The low frequency noise spectra of the HBTs were measured on wafer in the range of 330 Hz to 1 MHz avoiding harmonics of 60 Hz. The HBTs were arranged in a common-emitter configuration with bias applied to the base and collector terminals through batteries to minimize noise added by the power supplies. The system offered the added option of biasing the base via a high or low value of source impedance to study the effect of the input termination on the device output noise. With the input open circuited, the fundamental noise source at the input, S_{ib} is

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multiplied by h_{fe}^2, while with the input short-circuited, part of the input noise is shunted to ground via the base resistance and only a fraction $(R_b/ R_b+r_\pi)^2$ of S_{ib} is multiplied by h_{fe}^2 [9].

The output collector noise current was measured with a low noise transimpedance amplifier which converted the noise current into an amplified noise voltage and delivered the signal to a spectrum analyser. The automated system set and recorded the bias conditions and the device small signal current gain, h_{fe}. Prior to all measurements, a system noise calibration routine ensured that the added system noise did not corrupt the measured device noise. The temperature dependent measurements were performed on a heat chuck controlled by a thermocouple.

Devices of different emitter areas ranging from 10 μm^2 to 80 μm^2 were measured at collector currents of 0.5mA to 4mA with a fixed collector-emitter voltage of 2V. The noise was measured at three different temperatures: 25, 40 and 55°C. Several devices of the same kind were measured to ensure representative data.

RESULTS

$Al_{30}Ga_{70}As/GaAs$ HBT

The output noise spectrum for 30% Al emitter HBTs is shown in Figure 2. The measured noise shows a clear burst signature in the midband with the 1/f component appearing at very low and very high frequencies. Both components increase with collector current in the open and shorted input condition with the burst noise component showing an $I_c^{1.19}$ behavior.

In Figure 3, the temperature dependent spectrum at a fixed bias point (I_c=2mA, V_{ce}=2V) indicates that the roll-off frequency for the burst noise component increases at lower temperatures. By applying a Lorentzian single time constant trap model to the measured data, a thermal activation energy of 0.29eV is obtained which is consistent with the electron capture energy of deep level DX center traps measured in 30% AlGaAs [10].

$Al_{20}Ga_{80}As/GaAs$ HBT

In contrast to the 30% Al emitter HBT, the low frequency noise spectrum of the 20% Al emitter HBT shown in Figure 4 shows no sign of burst noise. The remaining noise has an ideal 1/f dependence with a $I_c^{1.14}$ behavior. It has already been pointed out that a lower Al mole fraction in the emitter-base region translates into lower burst noise because of the reduction in the DX center binding energy and occupation probability [10]. Furthermore, no temperature dependence is observed in the collector noise spectra indicating that thermally activated deep levels contribute negligible burst noise in these devices.

InAlAs/InGaAs HBT

The collector noise of the InAlAs/InGaAs HBT shown in Figure 5 exhibits similar behavior to the 20% Al HBT with pure 1/f behavior and no burst noise. Bias and temperature dependent measurements revealed a $I_c^{0.54}$ relationship and no variation with temperature. The weaker dependence of the output noise on the operating current when compared to GaAs-based HBTs stems from the slower variation of h_{fe} with I_c inherent in InP-based HBTs with lower non-ideal surface recombination currents.

NOISE SCALING

The effect of device area scaling on the noise is illustrated in Figures 6 and 7 for GaAs and InP-based HBTs, respectively. For the both Al mole fractions, the larger GaAs HBTs exhibited lower noise at 10 KHz for a given current. The noise in the InP-based HBTs was insensitive to the device area and depended solely on the operating current.

Despite the AlGaAs passivation ledge, the GaAs HBTs still suffer some recombination effects that are sensitive to the device perimeter. Smaller area devices typically have higher perimeter/area ratios and show higher noise associated with fluctuations in surface recombination velocity [6]. The noise behavior of the InAlAs emitter device suggests that the dominant noise source originates from a bulk process, independent of the perimeter/area ratio.

PHASE NOISE IN OSCILLATORS

The phase noise in oscillators should reflect the low frequency noise in HBTs under a short-circuit input condition since the high-Q resonator presents an RF short to the base terminal. The ouput noise in all the devices was substantially in the low source impedance configuration. Identical common-collector VCO topologies for 20 GHz fundamental oscillators were realized in $Al_{30}Ga_{70}As/GaAs$, $Al_{20}Ga_{80}As/GaAs$ and InAlAs/InGaAs HBT technologies [11]. As illustrated in Figure 8, both the 20% Al and the InAlAs emitter technologies showed a 10 dB improvement in phase noise at a 1 MHz offset over the 30% Al emitter HBT technology. Suppression of the burst noise and minimization of the 1/f noise translated into lower phase noise in oscillators.

CONCLUSIONS

The low frequency noise in HBTs was characterized as a function of emitter material, temperature, bias and device area. AlGaAs/GaAs HBTs with 30% Al exhibited strong temperature dependent burst noise in the low frequency spectra while the 20% Al and InAlAs emitter HBTs showed pure 1/f behavior. The output noise with a low source impedance termination provided lower output noise than with a high source impedance termination. Reduction of the burst noise by lowering the Al mole fraction and minimization of the 1/f noise by using an AlGaAs ledge or an InAlAs emitter resulted in overall lower device baseband noise and improved VCO phase noise.

ACKNOWLEDGMENT

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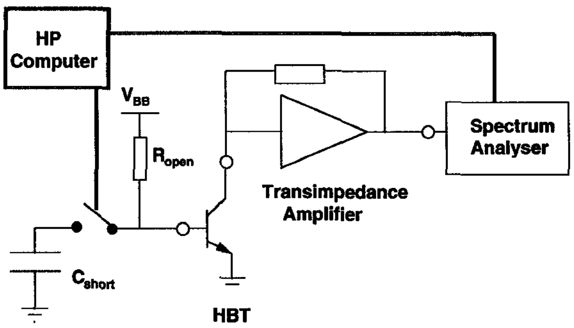

Fig. 1. The automated low frequency noise measurement system allows open and short circuit input terminations.

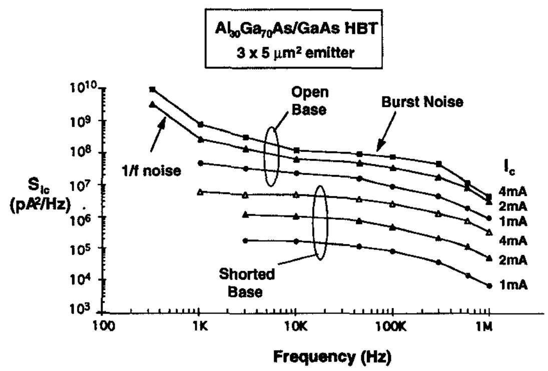

Fig. 2. Low frequency collector noise spectra of 30% Al emitter HBTs as a function of collector current and input source impedance.

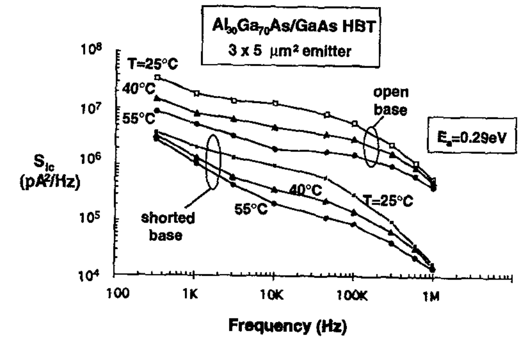

Fig. 3. Temperature dependence of the collector noise spectra of 30% Al emitter HBTs biased at I_C=2mA .

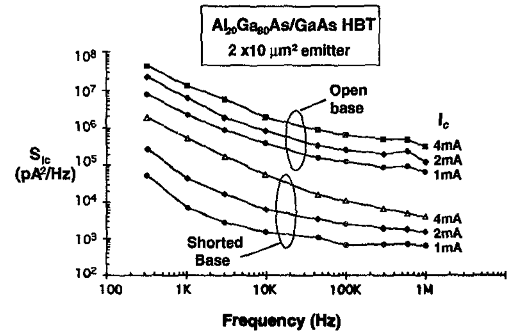

Fig. 4. Low frequency collector noise spectra of 20% Al emitter HBTs as a function of collector current and input source impedance.

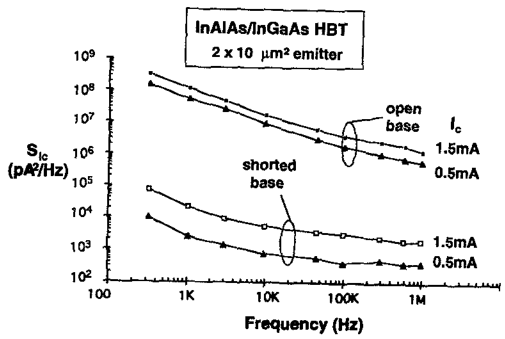

Fig. 5. Low frequency collector noise spectra of InAlAs emitter HBTs as a function of collector current and input source impedance.

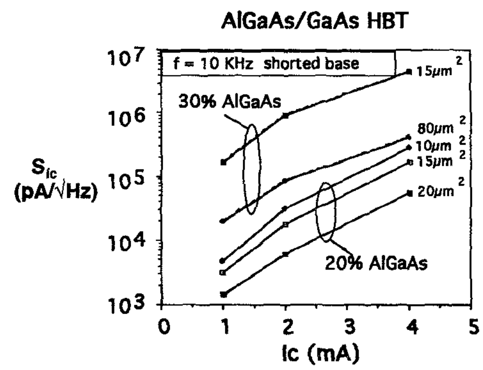

Fig. 6. The effect of area scaling on the collector noise of 20% and 30% AlGaAs/GaAs HBTs.

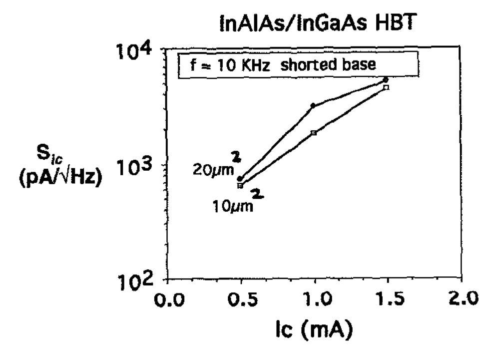

Fig. 7. The effect of area scaling on the collector noise of InAlAs/InGaAs HBTs.

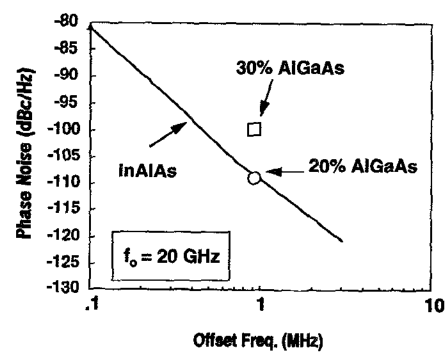

Fig. 8. The phase noise performance of 20 GHz oscillators implemented in the three HBT technologies.